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CAUSES, CONTROL, *And* PREVENTION OF GULLIES

At Various New England Locations

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Causes, Control, and Prevention of Gullies at Various New England Locations

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The formation of gullies within New England river valleys is associated with man's use of the land. Early settlers cleared the terraces by cutting and burning the native woodlands, and their successors continued to change the environment, with little thought of maintaining the hydraulic balance of watersheds. As a result, numerous seriously eroded areas have been created along streambanks and on the land surface.

The rate at which accelerated erosion can occur depends on such factors as the geology, soil, climate, and vegetative cover of the problem area. These factors are generally comparable throughout New England. However, the most serious gully erosion is within the Connecticut River Valley (fig. 1). Agriculturalists in the valley cultivate the land intensively, sometimes using practices that temporarily increase their income but also promote erosion.

In order to better understand the mechanics of gully erosion on New England river-terrace soils, two research projects were undertaken. One project was established to investigate causal factors of gully development; the other to evolve and evaluate methods for controlling gully erosion. The research was almost wholly confined to the Connecticut River Valley, but the comments and conclusions apply to the entire region.

CONNECTICUT RIVER VALLEY

The Connecticut River is the longest river in New England, and the Connecticut River Valley is often called the heartland of New England. It has affected the region's development because of its strategic location. Figure 2 is a map of the Connecticut River Basin, showing many of the places mentioned in this report.

Climate

New England is subject to the easterly movement of air masses that originate in Canada or the Gulf of Mexico. Less frequently, northeasters bring cool, moist air in from the North Atlantic. The climate of the coastal areas is affected by the ocean, but the topography has a greater effect on the weather in interior sections.

Precipitation.—Precipitation is fairly well distributed throughout

[1] Edwin A. Harre, conservation engineering technician, offered helpful suggestions and assisted in carrying out the procedures described in this report. Edgar H. Lawson, engineering aid, provided similar assistance during the project's initial stages.

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FIGURE 1.—View of Connecticut River from eroding first terrace. In background is a Vermont bottom-land farm. Westmoreland, N.H., 1959.

the year, with 3 or 4 inches during an average month. Unfortunately rainfall is variable from year to year and the reoccurrence of average conditions is not dependable. Along the coast, rainfall is distributed less favorably so that soil-moisture deficiencies are greatest in these areas. When high-value truck crops are grown, irrigation is commonly used throughout the region during the dry periods, which can be expected in July and August.

Although most rainfall is gentle, thunderstorms and hurricanes occasionally bring over 2 inches of rain in 24 hours to New England. One study showed that Springfield, Mass., in the Connecticut Valley had about one such storm annually during the growing season. At Hanover, N.H., the average was one 2-inch rainfall in 24 hours every 3 years (*18*).[2]

Average annual precipitation in the Connecticut Valley ranges from 36 inches in northern New Hampshire and northern Vermont to 48 inches near Long Island Sound.

Depending on the latitude, topography, and type and amount of precipitation, snow cover protects the land from late autumn until early spring. Nearly twice the amount of snow occurs in the upper valley as in the lower valley.

Temperature.—Temperatures in the Connecticut Valley are slightly higher than in the neighboring uplands. Average temperatures range from 17° F. in January to 69° in

[2] Italic numbers in parentheses refer to Literature Cited, p. 33.

FIGURE 2.—Map of Connecticut River Basin.

July in the upper valley and 27° in January to 74° in July in the lower valley (*13*). The length of the growing season is from 130 days in the north to 180 days in the south. Soil-temperature data are not available. However, the rate of soil freezing and thawing is a primary factor affecting soil erosion in New England.

Geology

The volume of flow in the Connecticut River is probably no less today than it was when the higher level terraces were formed. The rivers in this region have stepped terrace valleys. The base of many river terraces was determined by rock ledges, which are relatively resistant to water erosion (*6*).

The channels have not broadened much where the rivers met resistant bedrock, and terrace forms are not discernible. The terraces of the Connecticut River Valley do not maintain a uniform pattern and some may be only a few hundred yards long.

The overburden in the Connecticut River Valley is mainly glacial fill consisting of clay, silt, sand, gravel, and larger stone. It is generally deeper in the valleys and shallow or nonexistent in the hills (*17*).

Soils

The soils developed on glacial outwash and river terraces of the Connecticut Valley occur most often on level or gently sloping land. The physical character of these soils depends on the nature and thickness of the surface layer. Some surface layers are almost entirely sand; others are gravelly or fine sandy loams. These soils are highly permeable, and moisture relationships for crop growth frequently can be improved with irrigation. Soils are susceptible to erosion where terrace scarps are steep and where harmful cultural innovations have been introduced. Few farmers attempt to cultivate land with slopes steeper than 20 percent. Fields with slopes of less than 8 percent are usually selected for frequent tillage (*10*).

The soils that developed on the bottom land bordering the Connecticut River are also highly productive, but are subject to flooding. Compared to the terrace soils, the possibility of drought is less, as the water table is closer to the surface. Intensive vegetable growing is practiced on the high bottom phase of these soils, especially in Connecticut and Massachusetts. Poor management practices can cause serious erosion problems on these soils.

Hydrology

Nearly all the major New England river basins have flood damage each year. About half the estimated $32-million annual loss (at 1949 price levels) is attributed to flooding within the Connecticut River Basin. About 70 percent of the damage along the main stream occurs between Holyoke, Mass., and Hartford, Conn. A series of flood-control dams is being built, and dikes have been erected at several locations to protect developed areas (*17*).

Though the worst flooding in the lower valley was in August 1955, annual flood peaks usually occur during the spring thaw period, when the previously accumulated snow cover melts. The snow cover in the lower basin is usually depleted before melting occurs in the uplands. Snow accumulation is greatest about mid-March within the upper part of the Connecticut River watershed. At this time the water content averages about 1 inch for 6.2 inches of snow cover. The water content may be as low as 1 inch per 10 inches of snow at the extreme northern limits of the basin and at higher elevations in the mountains (*17*).

The average annual runoff for the entire basin is about 23 inches, or slightly more than one-half the average annual precipitation. More than 40 inches of annual runoff occur in areas of highest elevation in the White and southern Green Mountains. In the central and upper parts of the watershed about 50 percent of the annual runoff occurs in March, April, and May. Since less snow accumulates in the lower basin during the same months, the runoff in the lower basin is about 40 percent of the annual total (*17*).

Soil Erosion and Sedimentation

Clearing land for agricultural use, constructing transportation arteries, and other erosion-causing environmental changes increase the amount of soil carried from the land by flowing water. This soil material is eventually deposited as sediment. In navigable waters, dredging is a periodic necessity.

CAUSAL FACTORS OF GULLY DEVELOPMENT

Accelerated erosion is usually classified according to its degree of alteration to the landscape. Sheet and rill erosion removes topsoil. Evidence of its occurrence is usually obscured by tillage operations. Because of its incipient nature, this is the most widespread and damaging type of erosion. Serious sheet and rill erosion finally leads to gullying, which inflicts deep scars on the landscape. Gully erosion is the most dramatic form of erosion, and its results are difficult to obliterate.

The process of erosion may be considered to start with precipitation that falls on the highest part of a drainage area. Rainfall that does not percolate into the ground runs off in sheets and microchannels until sufficient flow combines to form a waterway. Water flowing from a higher to a lower elevation acquires momentum and tends to scour its channel. As more water enters the channel from the sides, the scouring action continues until the water is carrying its capacity of suspended load. Eventually the waterway reaches an outlet or major drainageway and, as the slope flattens, the water velocity decreases, and the suspended load may be partially deposited. These processes continue until equilibrium is nearly established.

Erosion processes remove soil material from the land at higher

elevations and gradually deposit it at lower elevations. Mass movements of soil and rock occur slowly in a nearly balanced environment. If the environmental factors are thrown out of balance and the rate of runoff is increased, the process of reestablishing a hydraulic gradient starts anew.

Gully development is one phase of landslides and mass movements of soil and rock. Sharpe (*22*) described and classified various mass-movement phenomena according to climate, rate, and material.

Previous Investigations

In 1936 a study of the causes of gullies and their growth in the Piedmont of South Carolina was conducted by Ireland, Sharpe, and Eargle (*11*). They found that gullies developed as a result of the loss of topsoil after long adherence to a single-crop cotton agriculture. They classified gully growth into four stages.

Channel-cutting into the A and B horizons is the first stage. At this time erosion is relatively slow, and control measures can best be undertaken. The second stage occurs when the base of the B horizon is penetrated and the gully begins cutting into the weak parent material. This stage is characterized by the headward migration of an overfall and plunge pool. It is the most violent stage of gully growth, and the least favorable for successful application of control measures. This stage ends when erosion is retarded because the channel reaches a graded condition under the control of some local base level. The third stage is one of adjustment. Slopes of the gully walls are reduced by weathering, slope wash, and mass movement. Vegetation gradually heals the gully. The fourth stage is characterized by the slow development and accumulation of new topsoil over the old scarred surface. Gullies in the third or fourth stage can relapse into the second stage at any time renewed cutting of the soil takes place.

Ireland, Sharpe, and Eargle (*11*) attributed gully formation to the concentration of flowing surface water by roads, ditches, and improperly constructed or maintained terraces. Many of the most serious gullies resulted from various types of drains that were originally constructed to control surface water and prevent erosion. However, successful diversions have controlled gullies and resulted in natural healing and stabilization. These authors recommended vegetative control within the gully to establish a graded condition rather than check dams or baffles, which did not seem practical to use in the weak parent material of the Piedmont soils. They minimized the effects of seepage and recommended the installation of drop inlet culverts to establish a local base level for erosion above the inlet. After lowering the water to the gully floor, they recommended releasing it with a minimum of scouring.

The cutting action described by Ireland and his coworkers is fairly descriptive of conditions in the Connecticut River Valley, except that a resistant B horizon does not predominate in the soil profiles of the river terraces. In most instances, stages one and two occur without interruption, and gully headwalls are cut vertically by surface runoff. When frozen sod still exists in the soil, it acts similarly to the B horizon, as shown in figure 3, and undercutting occurs. The overhanging frozen sod ultimately falls when warmer conditions prevail.

Thornthwaite, Sharpe, and Dosch (*24*) studied the relationship of climate to accelerated erosion in the Southwest. They did not discern any long-term changes in the characteristic semiarid climate of the area, but they attributed the lack of good vegetal cover and increased

FIGURE 3.—Surface runoff initiating gully. Note undercutting and large sod blocks in bottom of gully. Claremont, N.H., 1960.

erosion to the heavy concentration of human and animal population. Serious gullying correlates with the expansion of the livestock industry after the Civil War. Thornthwaite and his coworkers stated that natural stabilization is unlikely without a reduction in grazing and an increase in plant cover.

In water-scarce areas, the lowering of the ground water level through the cutting of deep gully channels is more damaging than the removal of soil by runoff. It is essential that the runoff be kept on the land instead of draining away immediately through deep gullies.

Montgomery (*16*) surveyed the erosion problem within the watershed of the Scantic River, which is a tributary of the Connecticut River. He reported that accelerated erosion was most severe where cultivation was intensive, even though there was no widespread misuse of slopes. Erosion was greatest in the spring, when the surface layer of frozen ground thawed. This process was further accelerated if rain or a layer of melting snow contributed to the amount of runoff. However, midsummer storms occasionally cause gullying.

Causes of Gullies at Various Locations

The most serious damage to agricultural land, while this study was being made, occurred during the spring thaw of 1960. At Vernon, Vt., a section of railroad track was washed out and the concentrated flow of water carried sediment onto the back borders of the first terrace. Runoff caused extensive damage along scarps of the first terrace on both sides of the river. Several

gullies were initiated and many eroded areas were enlarged.

Westmoreland, N.H.

Two gully sites were studied at Westmoreland, N.H. The principal topographic features of a 400-acre farm at the first site (*19*) are similar to those of many farm holdings along the Connecticut River. To take advantage of nearly level terrain, the State road is located east of the river on the back border of the first terrace.

To the east of the road are about 240 acres of sloping woodland with many visible rock outcroppings. This land is classified as a Hollis-Charlton rocky loam, a shallow upland soil not suitable for cultivation. The lower part of this wooded area, especially in the southern section, shows signs of severe wind erosion. Locust trees are gradually covering the area, but the soil is stabilizing slowly.

On the west side of the State road are farm buildings, cropland, and permanent pasture. In this area, as shown in figure 1, severe erosion is occurring.

The extent to which the Connecticut River contributed to the development of gullies at this site is not readily apparent. The farm is located at a bend in the river. In the spring, the main stream rises to inundate a broad flood plain on the Vermont shore. The current strikes the New Hampshire shore, eroding the bank and carrying off sediment, making room for further silt deposits at the drainage outlets of the gullies. The river aids in continuing the gully erosion process on this farm, but it was not a major factor in initiating the gullies.

Gully erosion was not a problem on the farm when the present owners acquired it in 1916. Prior to selling the farm, the former owner had cut the timber off the land east of the road. To the west of the road in the northern part of the cleared acreage, a Sudbury fine sandy loam was drained and put into cultivated crops. The major gully worked its way into this drained field along the path of the field outlet.

These two modifications of the environment—clearing the timber from the shallow soil on the hillside and draining the wet field into the problem area—contributed to the development of active gullies. Once the gullies were established, they drained the surrounding land and increased the tendency of the fields to become droughty.

Freezing and thawing action on the gully sidewalls also increased the rate of gully development. After the spring thaw, slumping may occur. Figure 4 shows an area where 20 inches of differential settlement occurred in the spring of 1959. This area is susceptible to sliding action.

The direction of gully development appears to have been affected by soil type. The soil map of this farm shows that the gullies tend to develop most readily on the loamy sands. However, the finer textured soils are also subject to gullying, particularly when drainage patterns are changed. Under the drying heat of the summer sun, sandy, noncohesive soil material on the slopes of the gully tends to slide. However, this activity appears to make only a minor contribution to gully enlargement.

An estimate of the land boundary bordering the river was made for 1916 when the owner acquired the property. Aerial photos taken in 1939, 1942, and 1952 were planimetered to estimate the amount of land taken out of agricultural production because of erosion. These data are shown in table 1. Erosion appears to be most rapid during the initial stages of gully growth. It is estimated that during the past 50 years over a million cubic yards of soil were washed off this farm into the Connecticut River.

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FIGURE 4.—About 20 inches of differential settlement above gully sidewall caused by freezing and spring thaw. Westmoreland, N.H., 1959.

TABLE 1.—*Estimated loss of agricultural land due to gully erosion and woodland encroachment on farm at Westmoreland, N.H.*

Year	Area of gullies	Between gullies	Woods bordering fields	Total area out of production
	Acres	*Acres*	*Acres*	*Acres*
1916	[1] 10			10
1939	26	5	13	44
1942	28	3	17	48
1952	30	4	16	50
1958				51

[1] Mostly streambank erosion.

At the second gully site at Westmoreland in 1959 a new farmowner planted corn for silage on erosion-susceptible, Walpole fine sandy loam and constructed a ditch along the fence line of his property to divert surface runoff water from his field and down the terrace scarp. The ditch started adjacent to a wet area on neighboring land, where Buxton silt loam predominates.

During the spring of 1960, runoff concentrated in the ditch and 3,175 cubic yards of soil material were eroded from the site in 1 to 2 days. Most of the damage extended from the scarp uphill 224 feet along the fence line. The maximum depth of the gully is 23 feet, with a maximum width of 48 feet. A finger of the gully extends 90 feet onto neighboring land.

Many clay lenses are apparent in the profile of the gully extension. Water tends to outlet above these lenses, and seepage flow has been seen during several visits to the site.

Claremont, N.H.

In 1957 a gully located on Agawam very fine sandy loam in Claremont, N.H., was selected for study. This gully is on a westerly 4- to 6-percent slope of the first terrace and is one of several gullies bordering a sparsely vegetated meadow. The parent material at this site is acid, gray, mica schist and to a less extent granite, gneiss, and weakly calcareous material. This gully was selected because of its moderate size and freedom from trash debris and remedial measures.

During the period of observation, the drainage area was limited to three-fourths of an acre. The winter of 1955, when the gully formed, was not unusual. Possibly the gully was caused by an abnormal concentration of surface runoff during the critical thaw period, which allowed exposed soil to be subsequently eroded at an accelerated rate. During the three spring seasons when it was observed, a low spot above this gully never approached overflowing, even when considerable gully damage was occurring below it.

Soil characteristics at this gully site are shown in table 2. The soil has a limited capacity to hold available water. The moisture infiltration rate. determined with a ring infiltrometer, was 1.6 inches per hour at the end of 60 minutes.

Most of the sorting of soil particles at this site is caused by spring and fall runoff. Some sorting also occurs when the main stream extends onto the land where the gully outlets.

Figure 5 shows the site as first visited in the fall of 1957. Sand swallow nests extending 30 to 40 inches into the sidewalls of the gully contribute to its growth. Large blocks of sod, about 4 by 4 feet, lay near the gully headwall, and about one-half cubic foot per second of seepage was flowing out of the tail of the gully. The gully floor was dry.

A survey was made in the fall of 1957 and each spring and fall thereafter until the spring of 1960, when the investigation at this site was terminated. Between 65 and 560 cubic yards of earth were carried off by eroding water each year.

A piezometer range was installed on a 45- by 45-foot grid, using 1-inch-diameter steel pipe, to measure piezometric levels near the gully each week. The piezometers were driven by hand to the impervious layer and varied in depth from 8 to 14 feet, depending on the depth of the soil mantle.

Subsurface water drained into the gully from the north and east during the spring. The height of water in the piezometers fluctuated seasonally, though some of the piezometers located higher on the slope had measurable quantities of water only during April.

In 1958, a 90° V-notch weir and a water-stage recorder were installed at the gully outlet. Surface runoff occurred for less than 10 days during the spring thaw period of 1959 and 1960.

The measured water levels at each piezometer were averaged to provide an average monthly level for comparison purposes. The relationship of precipitation to piezometer levels and runoff is shown in figure 6.

During 1960 the soil losses were five times higher than in 1959. The average water level in the piezometers was 25 inches and runoff was 1 acre-inch in April 1960. Similar values for April 1959 were 11 inches, or about one-half the piezometric level, and 3 acre-inches of runoff, or three times the amount of runoff measured in 1960. These data indicate that deep frost penetration retards soil infiltration and inhibits erosion; conversely, shallow frost penetration of the soil, warm temperatures, and ample precipitation promote soil erosion during the spring thaw period.

TABLE 2.—*Soil-moisture characteristics of gully at Claremont and of gully control at Piermont, N.H.*[1]

Horizon	Depth	Profile description	Bulk density	Soil water retention at—	
				⅓ atm.	15 atm.
GULLY AT CLAREMONT					
	Inches		*Gms. per cc.*	*Percent*	*Percent*
A_p	0–8	Very fine sandy loam; brown; weak, fine, granular structure; very friable.	1.16	14.4	4.4
B_{21}	8–12	Very fine sandy loam; yellowish brown; weak, subangular, blocky clods breaking to weak, fine, granular.	1.28	8.6	1.4
B_{22}	12–24	Very fine sandy loam; light olive brown; weak, medium, subangular, blocky clods; very friable breaking to weak, fine, granular.	1.23	7.5	1.4
C	24+	Fine sand, loamy, reddish brown, mottled with streaks, single-grained structure, loose.	1.33	8.1	1.4
GULLY CONTROL AT PIERMONT					
A_p	0–8	Loamy sand; brown; weak, fine, granular structure; very friable.	1.26	15.1	3.0
B_{21}	8–13	Loamy sand; yellowish brown; very friable, very weak, subangular, blocky clods breaking to weak, fine, granular.	1.23	14.4	4.2
B_{22}	13–19	Loamy sand; olive gray; single-grained, loose structure.	1.22	9.2	1.9
C	19–26	Medium sand, gray, loose, single grained.	1.32	6.0	.2

[1] Profile description from Harvel E. Winkley, Soil Conservation Service, and soil-moisture data from Eliot Epstein and Walter J. Grant, Agricultural Research Service

On March 31, 1959, within a week of the thaw period, a California boring rod was driven 4½ feet into the headwall near the bottom of the gully. There was no evidence that the rod had reached unfrozen soil. Considerable erosion occurred during the thaw that spring on the south-facing slope of the gully, but little erosion was noted on the opposite slope. Thermocouples were therefore installed obliquely on the north and south sides of the gully about 10 feet from the sidewalls to measure soil temperatures. Sensing elements made of thermocouple wire

FIGURE 5.—Sand swallow nests extending 30 to 40 inches into sidewalls of gully. Claremont, N.H.

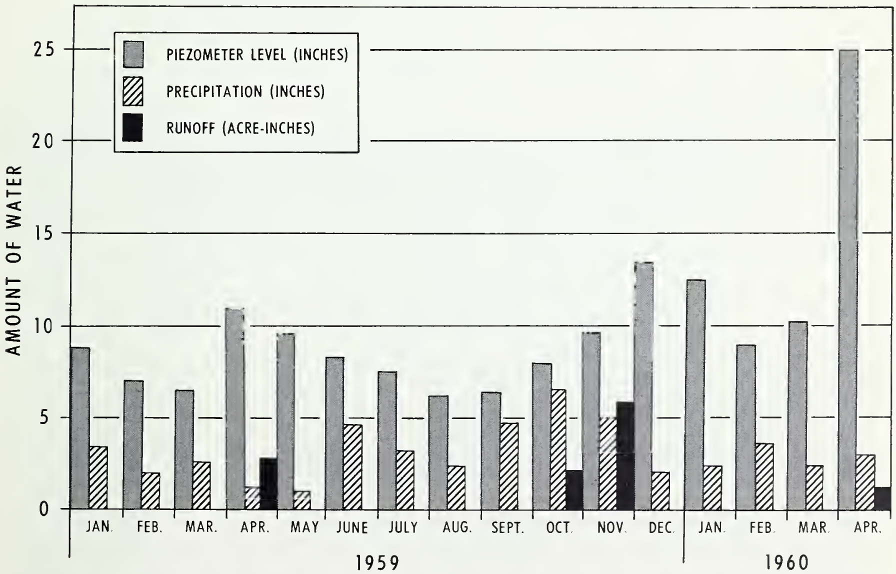

FIGURE 6.—Monthly comparison of precipitation to average piezometer levels and runoff for gully. Claremont, N.H.

were placed at ground level, at 1-foot intervals to 7 feet, and at 2-foot intervals to the depth of the impervious layer.

Figure 7 shows the soil temperatures on the north-facing and south-facing slopes at weekly intervals from early March until the week of the spring thaw in April 1960. Temperature measurements were made during daylight hours at the times indicated in the graph. These curves imply that the south-facing slope has less snow cover due to solar radiation and has lower soil temperatures during early March than the north-facing slope. As air temperatures rise, the north-facing slope also loses its snow cover, but being shaded it has lower temperatures than the south-facing slope. The south-facing slope warms rapidly during the thaw period. Sidewalls with this orientation readily slough as excess moisture released by thawing flows out of the soil.

Surface runoff, seepage, and freezing and thawing appear to be major causes of erosion at this site. The depth to bedrock is shallower here than it is on most terrace fields, and seepage throughout the year may remove fine soil particles from the soil mass without causing observable deterioration of the headwall. Seepage into the gully may be attributed to the confluence of many small drainageways, as interstitial flow probably increases near the walls of the gully.

Evidence of soil creep was observed on the slopes near the gully outlet. As a result, trees tended to incline upslope. This phenomenon was observed on slopes at other sites, and it may be attributed to seepage flow and freezing and thawing. Interstitial flow may weaken the soil mass by removing fine material and it may also affect frost heaving by making moisture available for migration to the freezing front with the onset of winter. The thawing process would release this excess moisture, and soil creep would occur on the frost-weakened slope.

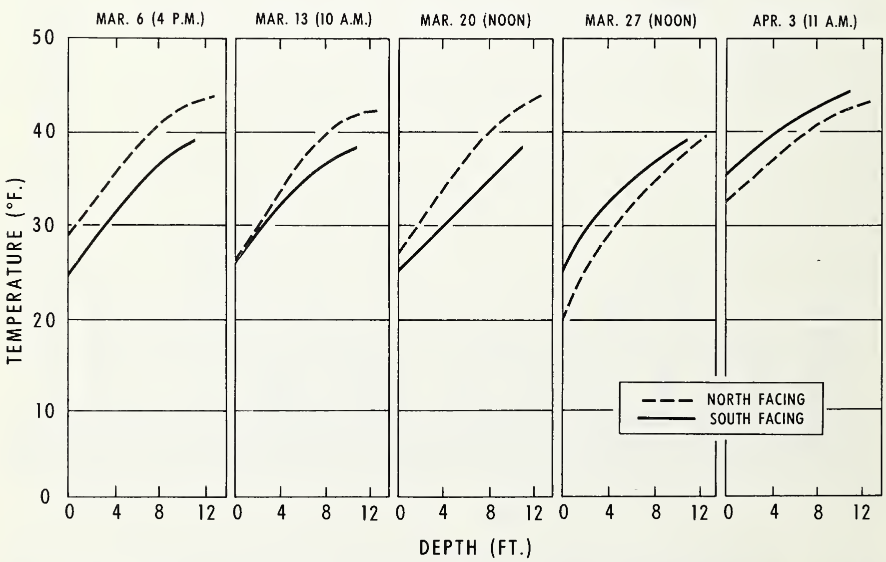

FIGURE 7.—Soil temperatures on north-facing and south-facing gully slopes prior to thaw period. Claremont, N.H., 1960.

Since 1,930 cubic yards of soil were moved from the gully between 1955 and 1960, with only 560 cubic yards accounted for during the 1957 to 1960 period, it appears that about 70 percent of the erosion activity occurred when the gully was first formed. However, the growth rate has been increasing during the 1957–60 period, indicating that soil instability will probably be present until some control measure is installed.

Orford, N.H.

The gully at Orford, N.H., shown in figure 8, is located on Suffield silt loam soil on the second terrace. Surveys were made in the fall and other observations were made at this site, though no instrumentation was established. The gully is on the northerly side of an eastward extension of the terrace. All but the westerly side slopes off steeply toward a meandering stream. The field was formerly a meadow and is occasionally used to pasture dairy animals, though the vegetal cover is sparse.

Varve clay layers can be observed in the gully, indicating that it is the site of a glacial lake that once occupied the Connecticut Valley. The varves are formed by alternate layers of silt or clay and coarse silt or sand. The former settled on the lakebed during tranquil periods, and the latter were deposited during turbulent spring flows. The thickness of the varves establishes layering patterns that can be used to measure the annual retreat of glacial ice from one location to another (*2*).

The area above this gully cavitates toward it, indicating that the varve layers tend to slide. This cavitation, or gradual slumping of the land, becomes quite steep near the rim of the gully. During the spring a mixture of clay and water

FIGURE 8.—Setting reinforcing rods in gully sidewalls to aid in making surveys and visual observations. Orford, N.H., 1957.

oozes downward along a circular slip surface.

Several trees have toppled into the gully, and along the rim some large trees have caused tension cracks. The root systems hang out in space, as shown in figure 9. In time these upright trees will fall, tearing large pieces of sod and soil from the gully rim. Most of these root systems extend laterally and are shallow near the gully. When the soil can no longer support the stresses induced by the weight of a tree and the forces acting on it, the tree will fall. The period of excessive loading due to the size and weight of a tree is sometimes manifested by tension cracks above the gully.

The meadowland where the gully is located was originally forested, and tree planting within the 1½-acre catchment area above the gully could be expected to reduce runoff. Some large trees are growing near the rim of the gully, and their removal would eliminate a hazardous condition that threatens to break off large masses of soil.

Durham, N.H.

In the spring of 1961 a gully was developing from subsurface flow within the Piscataqua River water-

FIGURE 9.—Gully in varve clay. This soil on the second terrace is very prone to slide. Tree roots overhead have shallow rooting depths. Orford, N.H.

shed near Durham, N.H. An area of Suffield silt loam on a small terrace bordering a tributary stream was sinking, as shown in figure 10. Water was flowing out of the streambank at the rate of 25 to 30 gallons per minute, and the turbid water was carrying suspended materials downstream. The muddy coloring of a large pond downstream was first noticed in 1960. In the spring of 1961 ground sinking occurred above the terrace slope, cutting into a farm road.

This ground sinking may be an occurrence of stream piracy, a situation caused by the burying of a weak channel by glacial action (*14*). Water was not flowing in the streambed, and was noted to be near the ground surface at an open well. Farther to the west a swampy area at higher elevation provided a source of water.

Test holes were bored at strategic locations to determine the subsurface profile. Soil and water samples were taken for laboratory analysis to aid in determining the factors causing the ground sinking. These investigations showed that the surface soil was underlain with olive clay, gray clay, sand, and in some instances gravel above the bedrock. It appears that some fine material was moving out of the sand layer.

Discussion of Causal Factors

Man's alteration of the environment is the principal underlying cause of accelerated erosion. When men clear the land of climax vegetation and introduce cultivated crops, they often establish an environment subject to wind and water erosion.

Water flowing over the surface of the ground is the major cause of gullying in New England. Only a small amount of surface runoff is necessary to maintain gully activity in a sandy river-terrace soil, as shown in figure 11. Although some gullies may form during July or August, nearly all of them start during the spring thaw period. At

FIGURE 10.—Ground sinking due to seepage on small terrace in Piscataqua River watershed causes "horns" or cracks on surface looking upstream. Durham, N.H.

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FIGURE 11.—Runoff causing gully erosion. Piermont, N.H.

this time precipitation and snowmelt water provide the greatest amounts of runoff.

Runoff causes gullying when it enters drainageways and diversions that are not maintained with adequate outlets. When established drainage systems are modified to accommodate highways and other structures, neglect to provide for the disposal of concentrated runoff also may create serious gullying.

Surface runoff is less apt to cause a gully slide when consolidated soil is protected by a deep frost, perhaps 4 feet or more in depth. When a soil mass is not protected by a watertight layer of frozen soil, surface runoff may seep into the soil and more erosion can be expected.

Several investigators (*8*, *12*, *23*) have shown that seepage rather than submergence is the important factor affecting slope stability. When slopes are submerged, failure will occur only when seepage water flows laterally through the soil causing instability. A thin layer of surface runoff may therefore destroy slope stability if seepage occurs.

Seepage into gullies may be an especially effective agent of slope instability. Gullies, being at lower elevation, may drain the fields in which they are located. Their effectiveness as surface drains depends on the amount of free water in the soil mass and the depth to the impervious layer. When the depth to bedrock is shallow, the flow of free water is more concentrated, and there is a greater chance for earthslides to occur along gully sidewalls.

Free water flows beneath the surface through small passages that develop among the interstices of the soil mass. The rate of interstitial flow increases with the volume of gravitational water. Since seepage converges where it outlets, the subsurface drainage system is highly developed along the gully sidewalls,

especially near the head of the gully. When seepage occurs slowly, the sidewalls may not obviously deteriorate, but piping or sorting of the soil particles may occur. However, such processes may not be discernible.

Seepage may develop gullies by removing soil material from below the surface. This is especially true when the depth to bedrock is shallow. Other investigators attributed gullying to ground sinking in the arid Great Plains region. Rubey (*21*) stated that ground sinking might be more active in humid than arid regions, but its effects might be masked by greater surface erosion.

Buckham and Cockfield (*5*) suggested that water at the time of spring thaw or after storms percolates into silty material and travels downward until a temporary water table is reached. At this point it travels nearly horizontally until it reaches a point on a gully wall or otherwise returns to the ground surface at a lower level. This body of saturated silt suddenly slides out, and a tunnel is formed, running back into the mass of silty soil. Seepage has been described as the principal cause of the gully at Durham, N.H.

Gullies may develop when freezing and thawing activity causes tension cracks at the top of slopes and exposes bare soil to the subsequent erosive forces of surface runoff. During the thaw period, south-facing slopes and gully sidewalls may warm rapidly, releasing excess moisture that causes the slope to slough. Thawing occurs more slowly on north-facing sidewalls, but differential settling along the freezing plane may occur. Areas subject to differential settlement eventually slide downward, extending the eroded area.

More information is needed to understand the effect of seepage and freezing and thawing activity on slope stability and soil creep.

The location of trees on slopes subject to runoff from higher elevations is seldom critical when the entire area is forested. When large trees border meadowland on the scarp of a terrace, they may subject the slopes to failure because of static or eccentric loading. The formation of tension cracks at the top of slopes and the exposure of bare soil due to tree toppling are often incipient stages of gully activity.

Armand (*3*) warned against planting trees with tall trunks near steep slopes, because the swaying of their crowns in the wind leads to landslides.

During dry summer periods noncohesive sandy soils on steep slopes may slide because of solar heating. In some places this is of consequence (*1*), but in the Connecticut Valley it is less important as a causal factor of accelerated erosion.

Several gullies have been attributed to the burrowing of rodents. Groundhogs often build burrows on terrace scarps, with openings above and below the brow of the slope. These burrows are enlarged as surface runoff passes through them, and slope deterioration occurs rapidly.

CONTROL OF GULLIES

When serious gullying occurs, an immediate and effective means of control is essential to protect the fields into which a gully is encroaching and to prevent sediment from moving onto the land below the gully.

Gullying may be controlled by modifying the factors that caused it. Changes in land use are a primary cause of accelerated erosion, but it is seldom possible to restore previous conditions. Other methods are usually employed to modify the en-

vironment. An effective control measure should reduce the velocity or quantity of water flowing through the gully, or prevent it from reaching the gully.

Runoff can be diverted to a stable channel to minimize the flow to a gullied area. When it is not feasible to provide a channel, mechanical structures may be installed. If properly designed, these structures can dissipate the kinetic energy of falling water and discharge the runoff into downstream channels with flow gradients that will not cause erosion. Drop inlet spillways, chutes, and pipe spillways are sometimes used for this purpose in New England.

Earth moving may be used to construct diversions that convey runoff water to a safe outlet. Terracing or contour stripping may retard runoff, conserve moisture, and reduce flow through eroding sites. Earth moving may also be used to construct vegetated waterways through the gully area.

Although vegetation may be effective by itself, it cannot be utilized until the planting area has been mechanically modified. This may be accomplished by filling in the gully or sloping the banks. Erosion-control structures are often required to protect erodible slopes from gullying. The maximum rate and amount of runoff will determine the type of gully control measure to be installed.

In forested areas of New England, open land that is no longer needed for crop production may be planted with trees. Judgment must be used in placing them near gullied sites. As trees grow in size, they may create or amplify landslides if they are too close to steep slopes. Trees take several years to establish themselves before they are fully effective in reducing runoff. Temporary control measures may be needed during the interim.

Previous Investigations

Investigators have recognized the beneficial effects of a good vegetative cover. Ree and Palmer (*20*) showed that short grasses could effectively control erosion in vegetated waterways. If it is necessary to utilize land susceptible to erosion for cultivated crops, protective grasses should be established along field borders and in other erosion-prone areas.

The location of trees, with respect to an eroded site, depends on the environment and the experiences of the conservationist. Armand (*3*) reported that tree belts are used to control erosion along rims of ravines and hollows in the Soviet Union. Plantings consist of a grass silt filter on the bottom of the gully and a tree belt fringing the gully top. The distance the trees are set back from the gully edge depends on the slope of the sidewalls. Grass is planted between the tree belt and the gully. Edwards (*9*) reported that willows or poplars should be planted in trenches up the side of the gully, so that the butts are below the gully bottom. He advised that trees should never be planted in the channel or at the foot of the sides, as they increase scour by causing water to swirl around them.

In recent years several studies were made to evaluate gully control measures. During 1947–49, Minshall (*15*) evaluated the condition of over 400 structures consisting of drop inlet culverts, concrete drop spillways, and masonry drop spillways that were constructed during 1933–38 in southwestern Wisconsin. He considered adequate and timely maintenance to be the first essential to insure satisfactory performance. He questioned the value of building permanent structures on problem sites where the watershed was less than 20 acres in extent. Sod flumes with concrete toe walls would prob-

ably be satisfactory where good sod could be established.

Harris [3] found that structures are not a basic requirement in gully control. Highly productive silt loam and silty clay loams with good subdrainage predominate in west-central Illinois. Gully control and rehabilitation in this area normally consist in constructing and maintaining a grassed waterway and a structural outlet for the waterway. Benefits from structures may be confined to small areas of nonproductive land, and even then their cost may not be justified. Tile drains can remove seepage flow and promote the establishment of vegetated waterways to control erosion.

Control of Gullies at Various Locations

When gully erosion occurs on agricultural land, nearly all farmers take some action or seek technical assistance. A common reaction is to fill a gully with trash or other debris. Trash on gully sidewalls prevents vegetation from getting established, and this conglomerate of refuse later slides downward, exposing the bare soil surface to erosion. This practice has widespread usage, but cannot be considered a gully control measure.

A few successful erosion control systems have been installed on terrace soils by farmers. Minor scouring caused by concentrated flow has been effectively controlled with rock rubble. These problem areas occur where surface runoff from cleared land enters tree-covered areas at the brow of scarps. Other farmers have reduced runoff by leaving sodded border strips along scarps.

[3] HARRIS, W. S. GULLY CONTROL WITHOUT STRUCTURES. Paper 59-701, presented at winter meeting of Amer. Soc. Agr. Engin., Chicago, Ill. 10 pp., illus. December 1959.

North Charlestown, N.H., and Westminster, Vt.

Two problem sites are described here because of their similarity. The first site is located on the westerly slope of the first terrace bordering the Connecticut River at North Charlestown, N.H. The initial cause of the gully is not known, but it seems to be related to land clearing. The area is well drained. The gully cuts into an 8-acre hayfield, as shown in figure 12.

The gully is now controlled by a dike 18 to 24 inches high. The drainage area is 15 acres, and the storage volume is about 57 acre-inches. The dike extends along the entire perimeter of the field at the terrace scarp. The gully has been stabilized and vegetation covers the slopes and floor of the gully. This control was installed over 40 years ago. During the spring thaw some water is pondea on the fields, but it seeps through the soil without damaging dormant grasses.

An effective control that seems to be indigenous to the Connecticut River Valley utilizes dikes to pond water on fields. Surface water then seeps downward within less than a week without damaging these well-drained soils.

The second problem site is located on the first terrace of the Connecticut River at Westminster, Vt. The stabilized gully borders a 36-acre field. The area directly in front of the gully has been scooped out in building a dike to prevent runoff from entering the gully. Water ponded on the field drains vertically within a week, without causing any problem. (Fig. 13.)

The control was installed in this Hartland silt loam soil about 1925. The infiltration rate was determined to be 0.40 inch per hour. However, the field is reseeded periodically, and the farmer has had no trouble with fine sediment sealing the soil surface.

FIGURE 12.—River-terrace dikes protect hayland, shown covered with snow, from gully encroachment. North Charlestown, N.H., 1959.

FIGURE 13.—Diked gully at Westminster, Vt., 1959.

Bedford, N.H.

This problem site [4] at Bedford, N.H., is located on a tributary stream of the Merrimack River. Bowmer Brook runs along the floor of an old gully about 20 feet below adjacent fields before outletting into the Merrimack River about 1½ miles to the east. Before the drop inlet control structure was installed, an active gully extended about 80 feet from the streambed into a fluvial terrace composed primarily of Nashua fine sandy loam. The subsoil is coarse sand that appears to have a texturally uniform profile from the top to the bottom of the gully. The gully developed along an old cowpath, and attempts were made to inhibit its growth by dumping rocks, trash, and other debris into it. At the time the control was installed, the gully was about 30 feet wide and 25 feet deep.

The gully was filled and a high bank was constructed above it so that water would not pass over the top edge of the terrace. The area was seeded with rye and winter vetch and held in place with 2 inches of straw or coarse mulch, secured with chicken wire. It was overseeded with redtop and orchardgrass. A concrete box inlet was installed within the ponding area, and the outlet conveys runoff into the flowing brook. This drop structure has been an effective control, though there has been some minor deterioration of the standing wall at the outlet. The earth moving, seeding, installation of a concrete box, and 18-inch corrugated metal pipe cost about $1,000.

Weathersfield, Vt.

The gully control at Weathersfield, Vt., is located on a dairy farm on the west bank of the Connecticut River. U.S. Route No. 5 is on the back border of the terrace, beyond which the terrace slopes uphill. Culverts are located under the highways, so that considerable quantities of water move in from adjacent areas to be concentrated in drainageways toward the river. The drainage area consists of 179 acres. This gully is located on the edge of a 70-acre segment of the drainage area, which is used for growing corn in rotation with hay. At the present time two gullies have been brought under control on this field.

The first gully apparently started around 1900. Its cause has been attributed to a woodchuck hole, but it is more likely that drainage into low areas concentrated the flow toward the riverbank. A topographic map of the area shows that there is a depression where the gully developed.

The second gully washed out of the northern end of the field, and it is also attributed to a woodchuck hole. This developed after about 4 years of snowmelt and precipitation. A diversion is now effective in preventing further damage. The sandy loam soil is Hadley high phase or Agawam.

In 1956 a vegetated waterway approximately 300 feet long was installed at the first gully. Brush and trees were cleared from the area. The channel of the waterway ranged from 16 to 24 feet wide on a grade of 7 to 10 percent. The control area of approximately 1 acre was seeded with red and alsike clover, birdsfoot trefoil, and redtop and was mulched. After scouring action in 1957, the lower section of the waterway was smoothed and reseeded. Part of the damage at that time may have been caused by the high water level of the river during the period of spring runoff.

In 1959 a large area was scoured at the bend of the waterway, and jute matting was laid down to protect a seeding of alfalfa, brome, and

[4] The site description is from the engineer's report prepared by Donald M. Stockwell, engineering specialist, Soil Conservation Service, Hillsboro County, August 1954.

birdsfoot trefoil. Several willow cuttings were also set along the river edge. The willow cuttings did not establish themselves, but the reseeding operation with the jute matting was effective. The waterway is in good repair at the present time. This control cost about $1,500.

Piermont, N.H.

Two gully control sites at Piermont, N.H., are described. At one site in 1956, after about 3 years of experimenting with metal chutes by Soil Conservation Service technicians, dry wells with defined catchment areas and a diking system were installed to control several gullies. These gullies were encroaching on a 68-acre field cropped to a corn-oats rotation. The 8-foot dry wells, constructed of two 4-foot-diameter concrete tiles, were placed in six catchment areas on the field. The dike was constructed along the perimeter of the field.

The dry wells are located near the fence lines, or outer perimeter of the field, and do not obstruct or create a hazard to machine operations. The soil type at this location is Windsor loamy sand. Its physical properties are similar to those described at the other gully control site at Piermont.

In the fall of 1959, logs were dragged over the dike, lowering the dike and reactivating the principal gully in the southeast corner of the field. About 5,000 cubic yards of earth moved onto the bottom land during the 1960 spring thaw. The toppling of trees added to the damage, as they tore away pockets of soil. The sediment was trucked up the terrace to be put back in place. Unfortunately the dike was not constructed to a sufficient height, and failure again occurred during the spring thaw of 1962.

One dry well and the low area around it were still saturated when the site was visited. Snow was observed in the bottom of the second dry well, shown in the lower left corner of figure 14. Water was dripping off the sidewalls and intermittent decay was occurring.

The use of dry wells near the edge of the terrace may be hazardous. Surface water may move into a dry well in excess of the seepage rate and cause the ground near the dry well to become saturated. As a result, ground water may temporarily rise near the dry well and cause slipping by saturating the slope. The greater the runoff, the greater will be this action, and consequently, the greater the danger to stability.

Unfortunately observations were not made at the site while erosion of the slopes occurred, and it now appears that the damage was caused entirely by surface runoff.

The field was reseeded the previous fall, and a dead furrow had been turned inward toward the field at the toe of the dike. It concentrated runoff, which flowed at a higher velocity toward the low part of the field. Poor maintenance of the dike resulted in excessive damage from runoff.

The farmer has been concerned that the sandy sediment discharged from the gully will prevent the full use of productive bottom land, as shown in figure 15. The design of the control has now been modified to equalize the drainage areas assigned to each dry well. The soil can effectively drain ponded water, and the control should be successful as now designed and installed. Seepage has not been observed at this site.

At the other gully control site at Piermont during the summer of 1957, Soil Conservation Service technicians installed an 8-foot dry well, constructed of two 4-foot concrete tiles. This dry well was installed to control a gully that was developing on the southerly side of an eastward extension of the first terrace along the Connecticut River. The field into which the gully was

FIGURE 14.—Extensive erosion that removed damaged dike and left dry well high and dry. Piermont, N.H., 1962.

FIGURE 15.—Sandy material covers productive bottom land after passing down scarp. Note first-terrace gully in upper right corner. Piermont, N.H., 1962.

encroaching slopes off steeply on all but the westerly side. A level diversion, or dike, was constructed around the field to protect the side banks and to assure drainage into the dry well.

In the fall of 1957 a weather shelter was installed to house a two-position air-ground thermograph and a water-stage recorder. Thermocouples were set in the soil 1 and 3 feet below the surface and at the bottom of the well, 8 feet below ground surface. The water-stage recorder measured the head above a sheet metal V-notch weir, which was cemented into the rim of the dry well. Snow markers, an 8-day recording rain gage, and a piezometer range on a 45- by 45-foot grid were installed near the gully. Piezometers were driven into a medium sand layer, which was observed in the gully profile, at 20 feet from the surface. Piezometric measurements were made weekly with no positive results. A 90° V-notch weir and water-stage recorder were installed at the gully outlet. This weir was abandoned in 1958, as no water was observed in, or measured flowing through, the gully.

Prior to installing the dike control, 3½ acres drained into the gully. One-fourth of an acre is still unprotected by the dike, and runoff drains into the east side of the gully head, causing continued gully development. During the summer, soil material moving downward on the side banks adds to the gully's growth.

In table 2 are given the soil-moisture characteristics of the Windsor loamy sand at this gully control site. The area is nearly level and well drained. The parent material is windblown or waterlain sandy deposits. The moisture infiltration rate was 15 inches per hour at the end of 60 minutes. The water-holding capacity is greater in the A_p and B_{21} horizons than in the horizons below. A compact layer occurs at 34 to 48 inches, and below 4 feet some less permeable lenses can be discerned. These lenses are not continuous and do not appear to affect subsurface flow.

Water has been measured flowing through the weir on the dry well during short winter thaws and the spring thaw. Most gully damage occurs during the spring thaw. At that time, flow into the dry well occurs concurrently with a decreasing water depth in the ponded area. The effectiveness of the dry well in removing surface water, as compared to surface infiltration within the diked area, is therefore obscure.

During 1957–62, water-stage records showed water above the weir notch in the dry well in only 2 years. Considerable gully erosion was observed within the Connecticut Valley in 1960. The depth of frost was less than 2 feet at Piermont, and slopes were very susceptible to sliding. Some erosion did occur from surface runoff on the east side of the gully, which is not protected with a dike, but the pond area effectively prevented serious runoff elsewhere. The level of water stored in the pond indicated the effectiveness of the dry well.

The installation of a dry well is predicated on the assumption that the 12.56 square feet at the bottom of the well will remain frost free. Faster infiltration into the soil at the bottom of the dry well facilitates the drainage of water from the diked area. The infiltration rate at the bottom of the well at this site is 2 inches per hour faster than the 15-inch-per-hour rate measured on the sod-covered surface of the field.

At noon on April 3, 1960, the stage height in the ponded area was 7.84 inches. The trace on the water-stage record shows a constant slope of decreasing depth until the stage height reached zero at 10:30 p.m. Planimetering the contours of the topographic map for the area shows that 2.04 acre-inches, or 7,660 cubic feet of water, drained from the field in 10½ hours. The average area

through which infiltration occurred was 4,150 square feet. It is questionable whether a dry well would be of value under these conditions.

The Windsor sandy loam at this site has a very high infiltration rate. A dry well will not materially increase the effectiveness of a diking system on this soil. However, there may be occasions when a dry well is necessary. Drainage from a field underlain with an impermeable layer might be expedited if the depth of the dry well extended into more permeable material.

Charlestown, N.H.

A gully was formed during the summer of 1958 on a dairy farm in Charlestown, N.H. Approximately 640 cubic yards of soil eroded from the scarp of the first terrace after a thunderstorm. The U.S. Weather Bureau substation at Claremont, which is 12 miles north, reported 4.94 inches of rain within 24 hours when the gully formed. This storm had a 50-year recurrence interval. Indiscriminate grazing of livestock on the slope and the use of a farm lane on the same slope by livestock contributed to the development of the gully.

A survey was made of the gully and its 7½-acre drainage area, and infiltration rates were determined. The farmer and technicians of the Soil Conservation Service installed an experimental river-terrace diking system. Because the farmer's residence is adjacent to the field, the height of the dike had to be limited.

The gully, which developed in Agawam very fine sandy loam, was filled, and a shallow pond was established behind the dike (fig. 16, *A* and *B*). The control had a ponded capacity of 8.1 acre-inches of storage. Lime, fertilizer, and a mixed seeding of redtop, creeping red fescue, winter rye, and crown vetch were applied to the control area (fig. 16, *C*). Fencing was installed to prevent the entry of livestock (fig. 16, *D*). Instruments were installed to measure precipitation, temperature, and snow cover.

Weekly temperature data show that the soil in the depression is more moist and tends to be colder, especially during the summer. However, the temperature differential between the pond area and the field that drains into it is less distinct during the winter, when snow cover settles in the depression, counterbalancing the effects of wetness.

Infiltration rates were determined each month within the ponding area and at a point of higher elevation nearby. They were less in the ponding areas than in the surrounding drainage area.

Washing occurred at the toe of the slope below the filled gully during the spring thaw of 1960. This damage was attributed to drainage and seepage along the face of the slope. A second dike was established closer to the scarp to further limit the amount of runoff draining downslope on the surface, and a toe drain was installed at the foot of the slope.

The ponding area held water for less than a week. On April 5, 1960, approximately 2 feet of water was observed in the ponding area, and 2 days later there was about 1 foot of water. About 22 acre-inches drained through the surface in this period.

For each drainage acre, 1.13 inches of surface water can be stored at this site. The spring thaw of 1960 was particularly devastating to terrace slopes, but this control performed satisfactorily.

Langdon, N.H.

A gully at Langdon, N.H., is located on the first terrace near the beginning of a farm road that goes down to river-bottom land. The gully started in 1955. The cause has been attributed to dragging logs up

FIGURE 16.—Views of gully before and after control measures were installed. Charlestown, N.H., 1959. *A*, Gully on sandy loam of first terrace; *B*, earth moving to fill gully and form pond; *C*, area seeded; note dike protecting problem area from surface water; *D*, realined fence (see *A*) along cattle path and control area in background fenced against cattle.

the road from the lower level, which made ruts along the side of the road. Subsequently, these ruts concentrated the flow of water downhill, and the farm road was threatened.

A river-terrace diking system was installed, based on providing 3 acre-inches of storage capacity for each acre of drainage. The gullied area was filled and the road repaired. Water from the drainage area, which was approximately 4 acres above the road, was ponded by constructing a dike, and a dry well was installed. The soil type is Merrimac fine sandy loam. The total cost of installing this control was about $125.

The actual storage volume achieved was 11.6 acre-inches, which is close to the storage capacity desired. The dry well consists of a 24-inch culvert pipe, which has been packed with gravel to encourage drainage from the area during the spring. This combination control, with both a dry well and a dike, effectively prevented further erosion along the farm road.

Westmoreland, N.H.

This gully control is located on a farm in Westmoreland, N.H., on the first terrace of the Connecticut River. The soil type is predominately Agawam fine sandy loam. The land was planted with a normally fertilized cover crop of oats in the fall of 1959. In the spring of 1960, runoff caused a large tree to topple on the terrace scarp. Within a day or two a gully formed in the exposed bank and removed about 2,700 cubic yards of soil.

Gully control measures have been installed. They consist of a diversion on the eastern side of the field, away from the river. A dike has been constructed along the entire edge of the terrace scarp, and trees near the scarp edge have been removed. The drainage area is 10 acres and the storage volume is 5 acre-feet.

Discussion of Control Measures

Accelerated erosion on New England river terraces can be effectively controlled by installing a dike along the escarpment to store water on the land. In the Connecticut River Valley, surface water detention is effective when 3 acre-inches of storage capacity are available for each acre of drainage area. Surface water ponded behind dikes on the highly permeable terrace soils usually drains vertically within 5 or 6 days after the spring thaw without damage to soil or crop cover. If water is observed in the gully or the soil depth is shallow to bedrock, seepage can be anticipated. Under these conditions, the gully should be filled and a toe drain provided. Table 3 shows the storage capacity in relation to the drainage area at several locations where diked gullies have been effective.

Dry wells are not needed at most sites, but they may be used when less permeable sublayers of the soil would impede drainage. When used, they should be placed a suitable distance from the scarp.

Since the cost of earth moving is nominal, 3 acre-inches of storage for each acre of drainage area may be installed at most sites. However, this criterion, which has been found effective where control measures have been installed, may not be feasible at all gully problem sites. The amount of storage required may be revised as more experience in using river-terrace dikes is gained.

The volume of storage capacity required to detain snowmelt water and precipitation during the thaw period may also be estimated from meteorological and hydrological data for New England. Figure 17 shows the least amount of precipitation that can be expected 2 percent of the time during the 4-week period, March 22 to April 18.

TABLE 3.—*Diked gullies under Agricultural Research Service observation*

Location of farm	Soil type	Installation	Date	Drainage area	Storage volume	Storage volume per drainage area
				Acres	*Acre-inches*	*Acre-inches per acre*
Piermont, N.H.	Windsor loamy sand.	Dike and dry well.[1]	1956	32.63	95.10	2.92
Do	do	do [2]	1957	3.40	10.40	3.06
Westminster, Vt.	Hartland silt loam.	Dike, farmer	1925	64.00	187.50	2.93
Charlestown, N.H.	Agawam very fine sandy loam.	do	1900	15.00	56.75	3.78
Do	do	Dike [1 3]	1959	7.50	8.50	1.13
Langdon, N.H.	do	Dike and dry well.[1]	1959	3.85	11.60	3.01

[1] Soil Conservation Service.
[2] Research site of Agricultural Research Service.
[3] Cooperative research installation of Agricultural Research Service and Soil Conservation Service.

These least amounts of expected precipitation can be modified to reflect the absence or presence of snowmelt water as a contributor to runoff.

At the time of the spring thaw, snow cover is negligible in the southern part of the Connecticut Valley, but it may still exist in the northern part. The ratio of runoff to precipitation can be estimated by using figure 18. North of the line labeled 1.0, the runoff is higher than precipitation because of the melting of the previously accumulated snow cover.

For example, using figures 17 and 18, the estimated runoff at Orford, N.H., and Hartford, Conn., can be determined. The average precipitation is 3.2 and 3.6 inches and the precipitation-runoff factor is 1.2 and 0.9, respectively. At these locations 3.8 and 3.2 inches of runoff can be expected about 2 percent of the time. This approximates the experimental value of 3 inches of storage capacity per acre that has been found effective.

Isoprobability maps can be drawn for various other precipitation probabilities using the Dethier and McGuire publication (*7*). A design frequency using the 2-percent probability data (1 in 50 years) is recommended where the storage volume for this control frequency can be installed. The earth-moving expense of providing protection will be nominal in most cases. Adequate freeboard and allowance for settling should be considered when establishing the height of a river-terrace diking system.

River-terrace dikes should be placed close to the escarpment, as small amounts of runoff cause serious erosion. Storage capacity is increased by using borrow material from the ponding area. The side slopes of the dike should be no steeper than 3:1 to facilitate sod maintenance. All trees on or near the top of terrace scarps should be removed before a dike is constructed.

When cattle are pastured on protected terraces, the ponding area

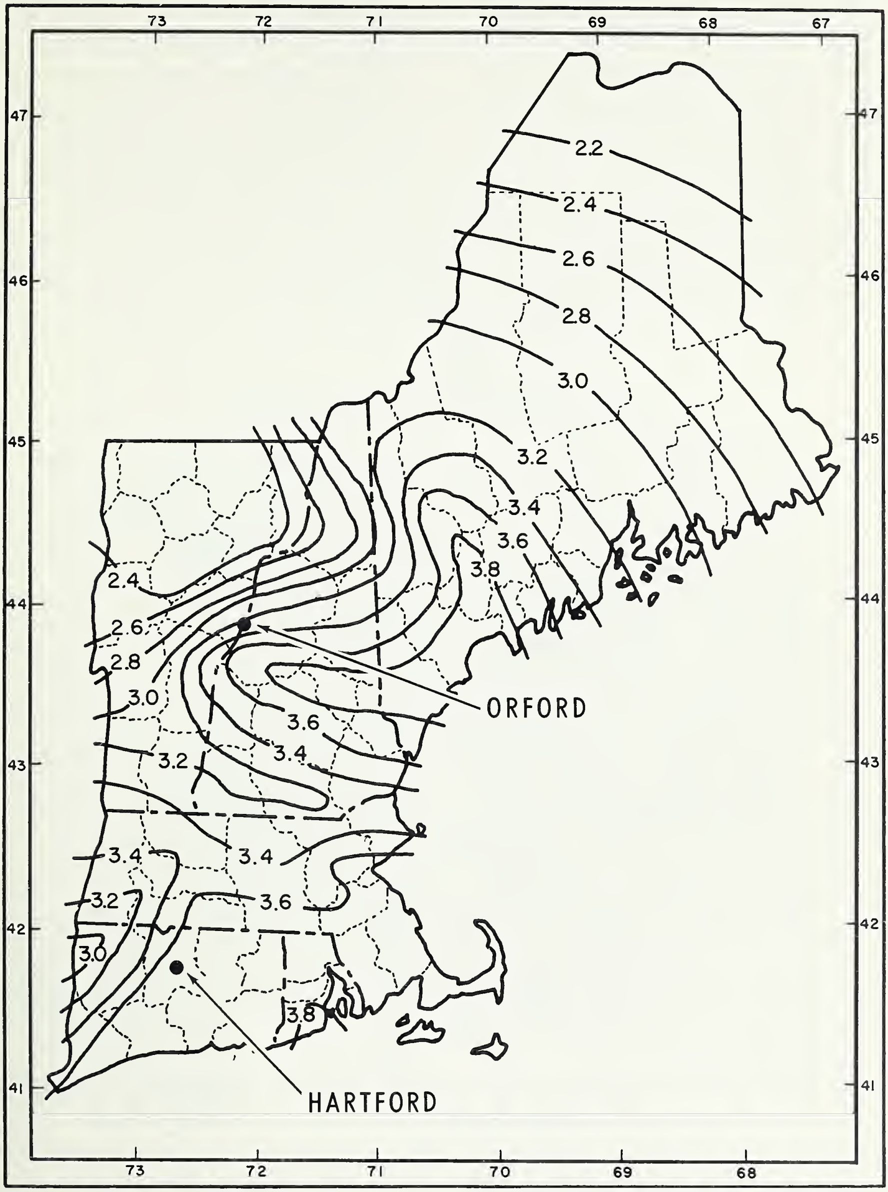

FIGURE 17.—Least amount of average weekly precipitation (inches) that will occur 2 percent of time during 4-week period, March 22 to April 18, for New England States.

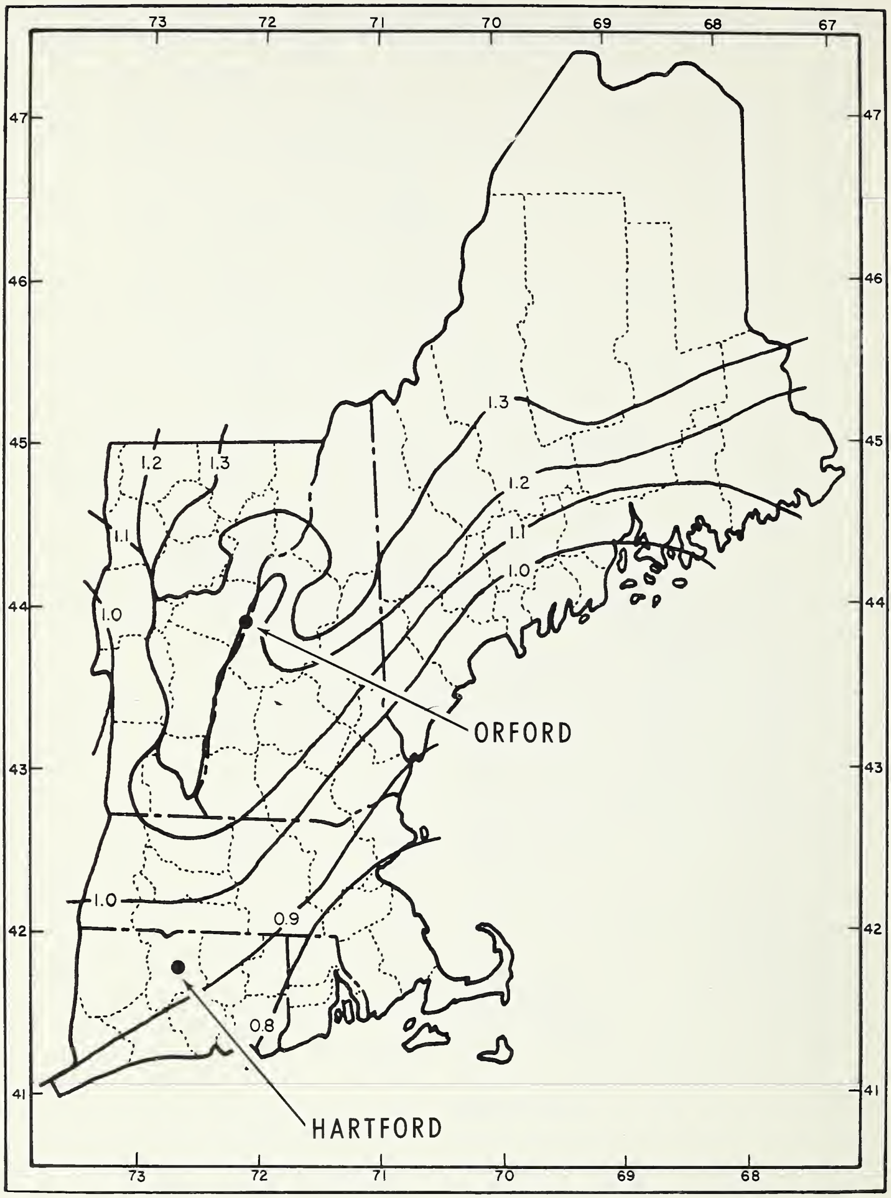

FIGURE 18.—Runoff-precipitation ratio (March–May) for New England States. (After Benson (4).)

should also be protected by fencing. Livestock compact the soil and reduce infiltration rates. Organic mulches and litter should be used when available, as they inhibit soil freezing and sealing of the soil surface. The depressed ponding area will catch a greater depth of snow and will be wetter than surrounding areas. This will slow soil freezing and reduce the depth of frozen soil while conserving spring moisture (*25*).

The dikes should be inspected periodically, especially in the autumn before snowfall. The burrows of rodents are often found on the top of slopes and should be filled.

Conservation practices should be used on the entire area above the dikes. The installation of dikes should be considered as part of the conservation plan for river-terrace farms to prevent gullies and to conserve moisture.

PREVENTION OF GULLIES

The methods of controlling gullies previously discussed are equally adaptable to the prevention of gullies. However, the first step in any program of gully prevention is to avoid changes in the environment that will unbalance a stable watershed. For example, selective cutting of timberland should be practiced, as indiscriminate clearing of forest land increases runoff and threatens the stability of slopes. Highway construction should be carried out with adequate provision for the disposal of drainage. When agricultural land is drained, adequate outlets should be provided. Conservation management should be employed on erosion-susceptible land to reduce the concentration of water runoff and the flow of runoff down slopes.

It has been shown that a thin layer of water may readily destroy slope stability if seepage occurs (*8*, *12*, *23*). The implications are clear; surface runoff should be kept off slopes whenever possible. The rate of runoff should be reduced by establishing dikes, diversions, and other water-control systems above and on slopes. A more widespread use of moisture detention systems would also be beneficial to crops planted in the sandy soils of river terraces.

In gully-prone areas the best practice is to use river-terrace diking systems to store runoff and conserve moisture. After a diking system is installed, periodic inspections must be made to assure its effective operation. Trees must be removed before they become so large as to be a problem. Groundhogs must be deterred from burrowing at the top of slopes. A good sod cover, mulch, or forest litter is needed on slopes. Bare soil is more subject to freezing and thawing and should have winter vegetative cover in the fall.

To prevent gully erosion within river valleys, the following recommendations should be considered:

(1) Aerial photos, soil maps, topographic surveys, and other information should be utilized to develop a plan that will conserve moisture for plant growth and prevent runoff from flowing down terrace scarps susceptible to erosion.

(2) Diking systems should be a part of the farm plan. For each acre of drainage area, 3 acre-inches of storage volume should be available for surface water. All trees should be removed from the edge of the terrace. The stumps should be cut near the ground and left in place.

(3) A land-use program should be developed with the farm operator to assure that good management practices are followed that will not promote runoff and erosion. Adequate outlets should be provided for

all drainageways and diversions, and lime, fertilizer, and seed should be used as necessary to maintain a good vegetal cover.

(4) A program of dike maintenance should be prepared. The sod cover should be cut annually and kept in good condition. A sod buffer strip should be maintained, and no furrows should be cut into the toe of the dike.

(5) Trees and wildlife should be under surveillance at all times. Livestock should be fenced out of areas where preventive measures have been taken. River-terrace fields should be inspected before snowfall, and groundhog burrows near terrace scarps should be filled to prevent piping. Bare soil should be covered with straw or other mulch to protect it during the following spring thaw period.

SUMMARY

Research was undertaken to determine the causes of gully development and the control and prevention of gully erosion at various locations in New England, primarily in the Connecticut River Valley.

Modifying the environment by clearing the land of timber, especially from shallow soil, for agricultural use is the principal cause of accelerated erosion. Surface runoff is the major cause of gullying in New England. Seepage may produce gullies by removing soil material below the surface, especially where the depth to bedrock is shallow. Seepage is particularly effective in destroying slope stability. Freezing and thawing cause cracks at the top of slopes and expose bare soil to erosion and surface runoff. Tree toppling may also expose bare soil. Some gullies are caused by the burrowing of animals. When these burrows are enlarged by surface runoff passing through them, slope deterioration develops rapidly.

Control measures should reduce the velocity and quantity of water flowing through the gully or prevent water from reaching the gully. River-terrace dikes will control gullies by ponding water on fields. Earth moving, terracing, and contour stripping may retard runoff. Trees properly planted near gully sites also may be effective in reducing runoff. In addition, dry wells are sometimes beneficial. Conservation practices should be used on the entire area above the dikes.

To prevent gullies, environmental changes that unbalance a stable watershed should be avoided, such as indiscriminate clearing of land that increases runoff and threatens slope stability. Adequate outlets should be provided for highway construction and for drainage of agricultural land. Dikes, diversions, and other water-control systems should be installed to reduce runoff on slopes. River-terrace diking systems are the best practice to store runoff and conserve moisture in gully-prone areas. Trees should be removed from the edge of terraces. A good vegetal cover is needed on slopes. Bare soil is more subject to freezing and thawing and should have a winter vegetative cover. Livestock should be fenced out of areas where control measures have been installed. Animal burrows near terrace scarps should be filled.

LITERATURE CITED

(1) ANDERSON, H. W., COLEMAN, G. B., and ZINKE, P. J.
1959. SUMMER SLIDES AND WINTER SCOUR. U.S. Forest Serv. Tech. Paper 36, 12 pp., illus.

(2) ANTEVS, E.
1922. THE RECESSION OF THE LAST ICE SHEET IN NEW ENGLAND. 120 pp., illus. New York.

(3) ARMAND, D. L.
1959. PREVENTING EROSION FROM HOLLOWS AND GULLIES BY TREE BELTS ALONG THEIR BROWS. Soviet Soil Sci. 1959: 147–156, illus.

(4) BENSON, M. A.
1961. PEAK DISCHARGE RELATED TO HYDROLOGIC CHARACTERISTICS IN NEW ENGLAND. Boston Soc. Civ. Engin. Jour. 48: 48–67, illus.

(5) BUCKHAM, A. F., and COCKFIELD, W. E.
1956. GULLIES FORMED BY SINKING OF THE GROUND. Amer. Jour. Sci. (5th ser.) 248: 137–141.

(6) DAVIS, W. M.
1954. GEOGRAPHICAL ESSAYS. Dover ed., 777 pp., illus. New York.

(7) DETHIER, B. E., and MCGUIRE, J. K.
1961. PROBABILITY OF SELECTED WEEKLY PRECIPITATION AMOUNTS IN THE NORTHEAST REGION OF THE U.S. *In* The Climate of the Northeast, Northeast Regional Research Publication. N.Y. (Cornell) Agr. Expt. Sta. Agron, Mimeo. 61–4, 302 pp., illus.

(8) EDELMAN, T.
1960. [THE FAILURE OF DIKES IN FEBRUARY, 1953.] Ingenieur 11: B35–B40, illus.

(9) EDWARDS, J. A.
1958. STRUCTURES AID GULLY CONTROL. South Austral. Dept. Agr. Jour. 61: 465–475, illus.

(10) GARLAND, L. E., ADAMS, H. R., and DONAHUE, R. L.
1956. SOILS AND THEIR CROP ADAPTATIONS IN NEW HAMPSHIRE. N.H. Agr. Expt. Sta. Bul. 424, 87 pp., illus.

(11) IRELAND, H. A., SHARPE, C. F. S., and EARGLE, D. H.
1939. PRINCIPLES OF GULLY EROSION IN THE PIEDMONT OF SOUTH CAROLINA. U.S. Dept. Agr. Tech. Bul. 633, 143 pp., illus.

(12) LAMBE, T. W.
1947. DISCUSSION. *In* Forbes, H., Landslide Investigation and Correction. Amer. Soc. Civ. Engin. Trans. 112: 407–410.

(13) LAUTZENHEISER, R. E.
1959. CLIMATES OF THE STATES—NEW HAMPSHIRE. U.S. Weather Bur. Climatography of U.S. No. 60–27, 15 pp., illus.

(14) LINSLEY, R. K., JR., KOHLER, M. A., and PAULHUS, J. L. H.
1949. APPLIED HYDROLOGY. 689 pp., illus. New York and Toronto.

(15) MINSHALL, N. E.
1953. EVALUATION OF GULLY-CONTROL STRUCTURES IN SOUTHWESTERN WISCONSIN. U.S. Dept. Agr. SCS–TP–116, 25 pp., illus.

(16) MONTGOMERY, P. H.
1939. EROSION AND RELATED LAND USE CONDITIONS ON THE SCANTIC RIVER WATERSHED, CONNECTICUT-MASSACHUSETTS. 27 pp., illus. Washington, D.C.

(17) NEW ENGLAND-NEW YORK INTER-AGENCY COMMITTEE.
[1955.] CONNECTICUT RIVER BASIN. *In* The Resources of the New England-New York Region. Pt. 2, chap. XXI, v. 1. New York.

(18) PALMER, R. S.
1958. AGRICULTURAL DROUGHT IN NEW ENGLAND. N.H. Agr. Expt. Sta. Tech. Bul. 97, 51 pp., illus.

(19) ——— and GRANT, K. E.
1961. GULLY DEVELOPMENT ON A NEW HAMPSHIRE FARM. N.H. Prog. Rpt. VII (1), pp. 10–12, illus.

(20) REE, W. O., and PALMER, V. J.
1949. FLOW OF WATER IN CHANNELS PROTECTED BY VEGETATIVE LININGS. U.S. Dept. Agr. Tech. Bul. 967, 115 pp., illus.

(21) RUBEY, W. W.
1928. GULLIES IN THE GREAT PLAINS FORMED BY SINKING OF THE GROUND. Amer. Jour. Sci. (5th ser.) 15: 417–422.

(22) SHARPE, C. F. S.
1938. LANDSLIDES AND RELATED PHENOMENA. 137 pp., illus. New York.

(23) Taylor, D. W.
1937. Stability of earth slopes. Boston Soc. Civ. Engin. Jour. 24: 197–246, illus.

(24) Thornthwaite, C. W., Sharpe, C. F. S., and Dosch, E. F.
1942. Climate and accelerated erosion in the arid and semi-arid southwest. U.S. Dept. Agr. Tech. Bul. 808, 134 pp., illus.

(25) Willis, W. O., Carlson, C. W., Alessi, J., and Haas, H. J.
1961. Depth of freezing and spring run-off as related to fall soil-moisture level. Canad. Soil Sci. Jour. 41: 115–123, illus.

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